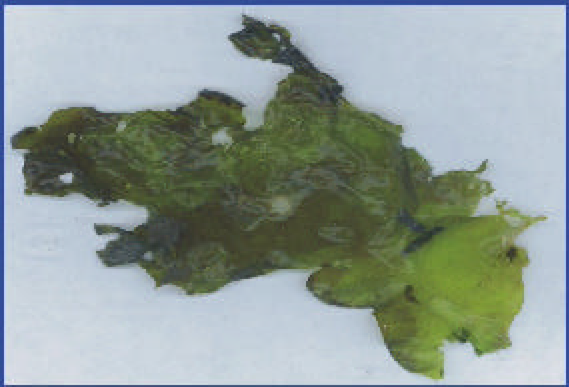
UNDERSTANDING THE ROLE OF MACROALGAE IN SHALLOW ESTUARIES



WORKSHOP PROCEEDINGS

Maryland Department of Natural Resources

Sponsored by

The Maryland Department of Natural Resources
Resource Assessment Service

In Partnership with:

The Maryland Water Monitoring Council

The Maryland Coastal Zone Management Program

The Assateague Coastal Trust

and

The Maryland Coastal Bays Foundation

PROCEEDINGS OF THE CONFERENCE:

UNDERSTANDING THE ROLE OF MACROALGAE IN SHALLOW ESTUARIES

Maritime Institute, Linthicum, Maryland
January 10 - 11, 2002

Edited By:

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Maryland Department of Natural Resources
Annapolis, MD

Contents

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The conference on *Understanding the Role of Macroalgae in Shallow Estuaries* was initiated by the Maryland Department of Natural Resources, Tidewater Ecosystem Assessment Division in partnership with the Maryland Water Monitoring Council, The Maryland Coastal Zone Management Program, The Assategue Coastal Trust and the Maryland Coastal Bays Foundation.

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Walter Boynton, University of Maryland, Chesapeake Biological Laboratory
Claire Buchanan, Interstate Commission on the Potomac River Basin
Carol Cain, Maryland Coastal Bays Program
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Kara Schwenke, Maryland Department of Natural Resources
Brian Sturgis, National Park Service
Cathy Wazniak, Maryland Department of Natural Resources
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Background

The Maryland Coastal Bays watershed lies within a single county in Maryland and offers a convenient and ever popular tourist attraction and favorable retirement area. Each year tourists flock to Maryland's Atlantic coast to take advantage of the beaches and coastal bays. The coastal bays are highly productive resources, offer recreational and commercial fishery opportunities and support boating and other popular water sports.

Increased development in the watershed has accelerated eutrophication. In similar systems, eutrophication initiates a shift in the dominant primary producer community from structurally-complex rooted vegetation (submerged aquatic vegetation or SAV) to less complex macroscopic plants (macroalgae) and eventually to microscopic unicellular plants (phytoplankton). Recent studies in the Maryland Coastal Bays have shown that macroalgae are abundant and in certain areas are the dominant form of vegetation. This finding has raised concern that nutrient enrichment may be causing changes in the ecosystem and degrading aquatic habitat quality. However, because there are few historic data on the macroalgae community in Maryland, there is uncertainty concerning whether the present community is natural or has increased in response to water quality changes. Anecdotal data suggest that the abundance and distribution of macroalgae that have been recently reported reflect increases over historical presence.

Foreword

The conference on *Understanding the Role of Macroalgae in Shallow Estuaries* was initiated by the Maryland Department of Natural Resources, Tidewater Ecosystem Assessment Division in order to understand the controls on, and dynamics of, the macroalgal community in the Maryland Coastal Bays. To date, little information was available on the distribution, abundance and species composition of macroalgae in the coastal bays. Recent concerns have been raised by researchers and citizens over observed increases in macroalgal abundance in submerged aquatic vegetation (SAV) and dead end canals. In response to these concerns, the Maryland Department of Natural Resources (DNR) began to consider its role in the ecosystem of the coastal bays. Through recent monitoring efforts, DNR has been able to document the presence and distribution of macroalgal genera in the coastal bays. These efforts have shown that the macroalgae community is more prevalent than previously believed and therefore should be considered in the eutrophication monitoring program for the Maryland Coastal Bays.

The objective of this workshop was to explore the role of macroalgae in shallow coastal ecosystems. Specifically, it focused on identifying the benefits and threats of various macroalgal species, gaining a better understanding of how macroalgae respond to nutrient enrichment and understanding how macroalgae may influence nutrient cycling. We also discussed recent monitoring efforts and explored ways to improve our present state of knowledge.

Workshop Goal:

To gain a better understanding of the role of macroalgae in the ecosystem in relation to nutrient dynamics and aquatic habitat.

Plenary Session

Dr. Walter Boynton opened the workshop with a word of welcome and a brief description of the agenda for the day. Dr. Robert Magnien followed with a description of the present state of monitoring and understanding of the Maryland Coastal Bays. He gave a brief description of the work that has been done to date that led up to the need for the workshop, and finished with describing the goals of the workshop.

Plenary Speaker: Responses of Shallow Marine Ecosystems to Nutrient Enrichment

Scott Nixon, Graduate School of Oceanography, University of Rhode Island, Box 17, South Ferry Road, Narragansett, Rhode Island

Abstract:
The success of simple predictive relationships such as the Vollenweider plot in limnology has encouraged marine ecologists to attempt to develop similar models relating pollutant inputs to ecological conditions in estuaries. Most of these efforts have focused on relatively deep (>5 m) river mouth estuaries and embayments where primary production is dominated by phytoplankton. Experimental nutrient enrichment studies of phytoplankton-based mesocosms at the Marine Ecosystems Research Laboratory (MERL) have confirmed that simple Vollenweider type relationships can be found between the rate of input of inorganic nutrients and annual mean chlorophyll concentrations and primary production. However, much of the coastline of the U.S. is characterized by estuarine ecosystems that are very shallow, and where most of the primary production is carried out by angiosperms, such as eelgrass, *Zostera marina*, epiphytic algae, drift and attached macroalgae, and epibenthic microalgae, rather than by phytoplankton. We have not been able to find useful relationships between nutrient input and the type of plant providing most of the primary production or between nutrient input and the amount of primary production in such shallow lagoon systems. Attempting to adjust nutrient loading for varying hydraulic residence time did not improve the models. Experimental studies using shallow lagoon mesocosms have shown that there is a large variation in the abundance of the various plant forms in these very shallow systems, and that simple Vollenweider models are not likely to emerge for this type of environment. However, it does seem that total system production increases with nutrient enrichment at very low rates of input, and that eelgrass does not persist when exposed to even moderate levels of fertilization. *Zostera* responds to inorganic nitrogen enrichment and to shading by increasing the rate of leaf elongation and decreasing the allocation of resources to below ground roots and rhizomes. This reduces or eliminates lateral branching of the rhizomes and causes a decline in the density of shoots. Based on mesocosm studies, we propose several indicators of eelgrass health, including the rate of leaf elongation, plant density, and the shoot: root biomass ratio that deserve further study and field testing.

Summary:
In his plenary address, Dr. Scott Nixon discussed the characteristics of shallow lagoon systems that are macrophyte dominated. Results from his mesocosm work indicated that these systems are atypical compared to phytoplankton driven systems. In phytoplankton dominant systems a clear relationship was established between nitrogen loading rates and water column concentrations, however, systems dominated by macroalgae did not respond directly to nitrogen loads. Because macroalgae have high and variable growth rates, and highly variable tissue nutrient ratios, it is difficult to model the macroalgal community response to nutrient enrichment.

Dr. Nixon discussed two factors that could impact modeling production in these shallow systems. First, he cautioned that flushing rates should be handled carefully when attempting to model eutrophication effects in lagoon-like systems. Because macroalgae are efficient at sequestering nutrients, corrections for flushing might result in an underestimation of the effects of increased nutrient loads. He also discussed the effects of temperature on system productivity. In his mesocosms, he found that a slight increase in temperature forced a shift in the dominant primary producer of the system.

In addition to examining controls on productivity, Dr. Nixon also discussed the value of macrophytes as habitat to finfish. In his mesocosm work, when predator-prey relationships were examined, fish in tanks dominated by submerged aquatic vegetation (SAV) were more efficient at avoiding predation than those in macroalgae-dominated tanks.

In closing, Dr. Nixon described the challenges in monitoring and understanding the role of macroalgae in shallow lagoons. He identified a list of challenges in predicting drift macroalgae community dynamics as follows:

- Effects of temperature, salinity, oxygen, age, reproductive state, etc. on production and respiration are not well described for many species
- Tumbling and layering may create variable and complex light exposure
- Highly variable stoichiometry
- Very patchy distribution, which may reflect transport and accumulation as well as growth
- Transport and accumulation difficult to model from tidal currents and bathymetry alone
- Vertical position in the water column may vary depending on biomass, photosynthesis, etc.
- Reproduction triggered by complex or unknown environmental cues and "age"
- Time of death and initiation of decomposition difficult to identify
- Grazing important in regulating biomass accumulation

Selected References:

Nixon, S.W., S.L. Granger and B. L. Nowicki. 1995. An assessment of the annual mass balance of carbon, nitrogen and phosphorus in Narragansett Bay. Biogeochemistry 31: 15-61.

Nixon, S., B. Buckley, S. Granger and J. Bintz. 2001. Reponses of very shallow marine ecosystems to nutrient enrichment. Human and Ecological Risk Assessment: Vol. 7, No. 5: 1457-1481.

Session I

Habitat Value and Threats of Macroalgae in Shallow Marine Systems

This session included presentations focused on the role of macroalage as habitat for fish and blue crabs, and examined the potential impact that macroalage blooms can have on submerged aquatic vegetation.

Seaweed Beds as Habitat for Juvenile Blue Crabs

C.E. Epifanio, R. A. Rodrigues, and T. E. Targett, Graduate College of Marine Studies, University of Delaware, Lewes, DE 19958

Abstract:
We investigated the value of macro-algal (seaweed) beds as juvenile habitat for the Atlantic blue crab *Callinectes sapidus*. The two-year study was conducted in Rehoboth Bay, a lagoonal estuary in the Middle Atlantic Bight along the east coast of North America. Seagrass meadows do not occur in Rehoboth Bay, and submersed aquatic vegetation consists entirely of macroalgae. Quantitative samples were collected from both vegetated and unvegetated, shallow-water habitat with a custom-built throw trap. Results indicate that seaweed beds provide important habitat for juvenile blue crabs, beginning at settlement and continuing until the crabs reach a carapace width of about 40 mm. Average abundance of juveniles in seaweed beds was nine times greater than in adjacent unvegetated habitat, and maximum abundance in the beds reached weekly mean values >80 crabs m^{-2} during periods of high recruitment in early autumn. Mean size of individual crabs was 15 mm in carapace width when sampling began in May; these crabs had settled the previous autumn and had overwintered in the bay. Mean size continued to increase through early summer, and the crabs had reached a mean carapace width >30 mm by August. These 30-mm crabs disappeared from the beds in mid-August and were replaced by newly metamorphosed juveniles <10 mm in carapace width. Very small crabs were common in the beds throughout September and were still abundant when sampling was completed at the end of October. Mean size of the crabs did not increase during this period, probably a result of overlapping cohorts of new recruits and post-settlement predation on each cohort. Our results indicate that seaweed beds provide nursery habitat for blue crabs that is comparable to that of seagrass meadows. Therefore, protection of healthy seaweed beds is critical to the success of blue crabs, especially in estuaries where seagrass meadows are non-existent or have shown recent decline.

Summary:
Dr. Charles Epifanio described his work in examining the role of macroalgae as habitat to blue crabs. He described the condition of the Delmarva watershed,stating that the watershed is dominated by agriculture (principally chicken farms), and in the last decade has seen increased urban development. Coupled together, these land use changes have led to significant increases in nutrient loads. These loads in turn spurred increases in macroalgal growth. The socio-political response to macroalgae is to harvest it, because it dies, washes to shore, and decomposes causing nuisance odors. Resource managers have, however, raised the concern that harvesting of macroalgae may cause reduction in finfish and blue crab stock due to significant by-catch rates. Managers argue that in the absence of SAV, macroalgae offer a suitable habitat for juvenile crabs and finfish. Epifanio investigated the value of macroalgae as habitat to blue crabs. He conducted a two-year study, where they compared vegetated and adjacent unvegetated habi-

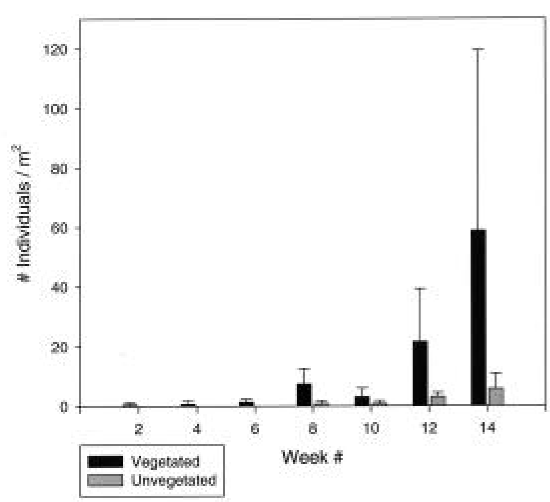


Figure 1. Number of crabs per week in vegetated verses unvegetated sites.

tats using a chi-squared design, and found very significant results favoring vegetated areas. Their results showed that the mean number of crabs per cubic meter was greatest at vegetated sites (figure 1). He stated that other researchers have found similar results in SAV and thus concluded that macroalgae beds are the analog of SAV in other systems, and in the Delmarva system macroalgae beds are the habitat.

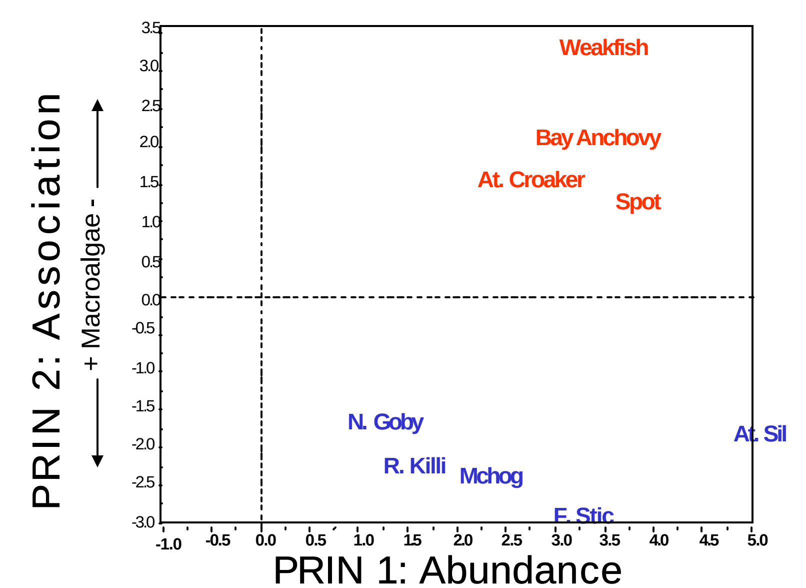
Seaweed being harvested in Delaware.

Seaweed as Habitat for Resident Fish Species

John Clark, ***Delaware Department of Natural Resources and Environmental Control, Little Creek, Delaware***

Abstract:
Primary productivity in the nutrient-enriched tidal tributaries of Rehoboth and Indian River Bays was predominantly phytoplankton and macroalgae. The fish communities of phytoplankton-dominated and macroalgae-dominated sites were compared to determine their differences. Fish were sampled with a 10-ft. trawl net twice monthly at twelve sites in four tidal tributaries of Delaware's Inland Bays during May through October in 1999 and 2000. Water quality also was measured and the volume of macroalgae trapped in the net during a sample was used to categorize macroalgal production. Although most fish species were caught at both macroalgae and phytoplankton dominated sites, analysis indicated the distribution of certain species, mainly of vegetation-associated resident species (e.g. fourspine stickleback, rainwater killifish), was skewed toward macroalgae-dominated sites while the distribution of others, mainly juveniles of migratory species (e.g. weakfish, spot), was skewed toward phytoplankton-dominated sites. Several sites changed from macroalgae to phytoplankton dominance during a sampling season and showed a corresponding change in their fish communities.

Summary:
Mr. John Clark presented a summary of the fish work that he had conducted in the Delaware Inland Bays. He sampled fish communities in tidal creeks using a 3.1m otter trawl. The amount of macroalgae that was gathered in the trawl was classified. Mr. Clark evaluated historical fisheries records and showed that there had not been any noticeable changes in fish community since the late 1950's. Using principal components analysis, he also examined the association of various fish species with macroalgae (figure 2). He found that sites where macroalgal abundance was high, resident species of fish were prevalent. Where macroalgal abundances were lower, migratory fish dominated. Though not experimentally tested, Mr. Clark noted that fish tended to prefer red algae, *Agardhiella spp.* more than the green alga, *Ulva latuca*. Mr. Clark also compared his algal data with water quality measures that were available, and did not find any apparent relationships.



Top scoring fish species plotted against the first two principal components.

(N. Goby=Naked Goby, R. Killi=Rainwater Killifish, Mchog=Mummichog, F. Stic=4-spine Stickleback, and At. Sil=Atlantic Silverside)

Figure 2. Results of Principal Component Analysis showing fish species associated with vegetation.

Selected References:

Sogard, S.M. and K.W. Able. 1991. A Comparison of eelgrass, sea lettuce macroalagae, and marsh creeks as habitats for epibenthic fishes and decapods. Estuarine, Coastal and Shelf Science 33:501-519.

Targett, T. E., C.E. Epifanio, and R. A. Rodriguez. 2000. Importance of sea lettuce and other marine macroalgae to fishes and macroinvertebrates of Delaware’s Inland Bays. Final Report to Delaware Department of Natural Resources and Environmental Control. University of Delaware College of Marine Studies.

Timmons, M. and K. Price. 1996. The macroalgae and associated fauna of Rehobeth and Indian River Bays, Delaware. Bot. Mar. 39:231-238.

Macroalgal Canopies Contribute to Eelgrass (*Zostera marina*) Decline in Temperate Estuarine Ecosystems

Jennifer Hauxwell [1], *Just Cebrián* [2], *Christopher Furlong, and Ivan Valiela*, [1]Boston University Marine Program, Marine Biological Laboratory, Woods Hole, MA 02543, [2]Dauphin Island Sea Lab, 101 Bienville Boulevard, P.O. Box 369-370, Dauphin Island, AL 36528, USA

Abstract:
Loss of eelgrass (*Zostera marina*) habitat from temperate estuaries worldwide often coincides with increased macroalgal accumulations resulting from increased delivery of anthropogenic nitrogen. We conducted macroalgal enclosure/exclosure experiments during summer 1998 within eelgrass populations in two estuaries of Waquoit Bay, MA, USA, to evaluate how increased macroalgal biomass affects density, recruitment, growth rate, and production of eelgrass. One estuary featured a low nitrogen loading rate and sustained a relatively pristine eelgrass population with a 2-cm high macroalgal canopy. The other estuary had a six-fold higher nitrogen loading rate and a declining eelgrass population with a 9-cm high macroalgal canopy. Experimental units were 1 m x 1 m plots of eelgrass fenced within 50-cm high plastic mesh that excluded or included macroalgae at canopy heights ranging from 0 to 25 cm. In both estuaries, rates of eelgrass loss increased, largely a result of decreased recruitment, and growth rates decreased (due to decreased rates of leaf appearance) with increasing macroalgal canopy height. Aboveground summer production in both estuaries decreased exponentially as macroalgal canopy heights increased. We conclude that macroalgal cover is a proximate cause for loss of eelgrass in the higher N estuary since, upon removal of macroalgae, we observed an increase in shoot density, a 55% increase in summer growth, and a 500% increase in summer above ground net production. Based on summer growth data and density of shoots in our experimental plots the following spring, we suggest that the negative impacts of macroalgal canopies persist, but also that eelgrass recovery upon removal of macroalgae may be possible.

To identify the mechanisms by which macroalgae potentially inhibit eelgrass production, we measured changes in nutrient and oxygen concentrations resulting from macroalgal canopies, and estimated the relative importance of summer standing stocks of phytoplankton, epiphytes, and macroalgae to potential shading of eelgrass in both estuaries. We document both (1) unfavorable biogeochemical conditions (lowered redox conditions and potentially toxic concentrations of NH_4^+) imposed by the presence of macroalgal canopies and (2) potential light limitation of eelgrass by standing stocks of producers in the higher N estuary, with estimates of light reduction via macroalgae numerically more important than light sequestration by phytoplankton and epiphytes for newly recruiting shoots. Increased macroalgal biomass associated with increased nitrogen loading to estuaries can lead to eelgrass disappearance, and we identify an approximate < 9-12 cm critical macroalgal canopy height at which eelgrass declines.

Summary:
Dr. Jennifer Hauxwell described her research on the influence of macroalgal canopies on eelgrass (*Zostera marina*) productivity. Experimental plots were established in natural eelgrass meadows in two estuaries of Waquoit Bay, MA, USA; one site featured a low nitrogen loading rate (5 kg N ha^{-1} y^{-1}), a healthy eelgrass meadow, and patchy canopies of macroalgae < 2 cm high; the second site featured a 6-fold higher nitrogen load, a declining eelgrass meadow, and a more uniformly distributed canopy of macroalgae >9 cm high (Figure 3). Macroalgal canopy heights were manipulated within the experimental plots (0 to 25 cm high) at both sites and effects on eelgrass shoot density and growth were measured. Their observations showed that eelgrass was rapidly lost from plots containing macroalgal canopies > 9 cm, but was also lost in the control plot in the higher nitrogen estuary. Eelgrass growth rates were found to decrease linearly as macroalgal canopy heights increased. Upon removal of macroalgae in the higher nitrogen estuary, eelgrass density and growth increased rapidly. It was concluded that recent areal loss of eelgrass from the higher nitrogen estuary was likely a result of the naturally-occurring canopy of macroalgae that persists there. While eelgrass was lost from the higher nitrogen estuary (nitrogen loading rate of 30 kg N ha^{-1} y^{-1}), nitrogen loads to other estuaries of Waquoit Bay can exceed this value over 10-fold as a result of urbanization within watersheds. Hauxwell et al. also identified potential control mechanisms by which macroalgae exclude eelgrass and found that thick canopies of macroalgae caused low oxygen conditions and toxic ammonium concentrations around eelgrass roots and buried portions of leaves. They also demonstrated that light may have been limiting to

newly recruiting plants in the higher nitrogen estuary, as a result of macroalgal shading. In conclusion, they argue that eelgrass and macroalgae are very sensitive indicators of nitrogen loading.

Selected References:

Hauxwell, J., J. Cebrian, C. Furlong, and I. Valiela. 2001. Macroalgal canopies contribute to eelgrass (*Zostera marina*) decline in temperate estuarine ecosystems. Ecology 82:1007-1022.

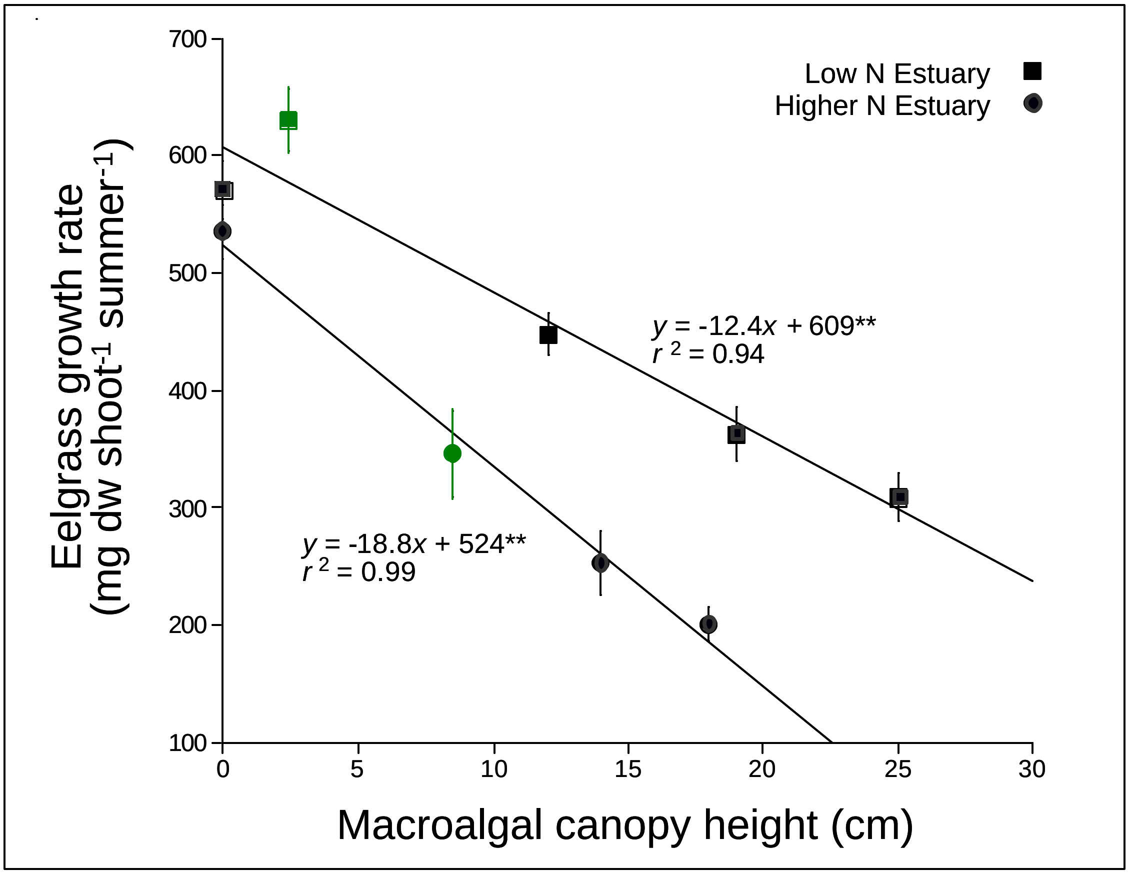
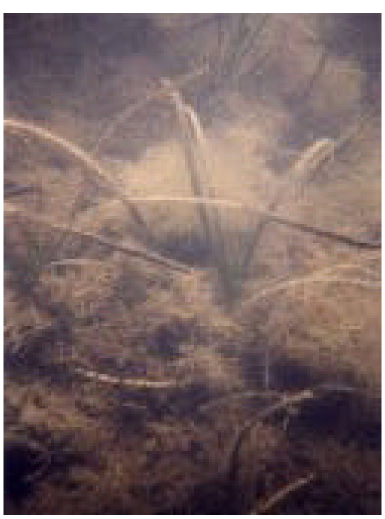


Figure 3. The relationship between macroalgal canopy height and Eelgrass growth rate.



Eelgrass surrounded by macroalgae.

Seagrasses in the Delmarva Coastal Bays: Where did it go, Why did it come back and Where is it going?

Robert J. Orth, Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Pt., VA 23062

Abstract:

Seagrasses, once a common sight in all coastal bays of the Delmarva Peninsula in the early part of the 20th century, completely disappeared (or were thought to) in the early 1930's, attributed in part to both a wasting disease phenomena that influenced eelgrass populations in the entire Atlantic basin and the disastrous 1933 hurricane. Recovery began either from small remnant stands that survived the disease and storm, or reputed transplants from Chesapeake Bay in the 1940's. Recovery of Delaware's seagrasses ended by the 1960's with seagrasses no longer present by the end of the decade, most likely due to anthropogenic inputs of nutrients that led, in part, to massive macroalgal blooms that smothered the seagrass. Seagrasses in Maryland's Coastal Bays (Chincoteague, Sinepuxent, Isle of Wight and Assawoman bays) along with seagrass in the Virginia portion of Chincoteague Bay have been rapidly expanding over the last 15 years as documented by the VIMS annual SAV monitoring program. The increase is being fueled, in part, by the larger number of propagules being exported from the expanding seagrass. While the expansion suggests water quality requirements for seagrass growth and spread are being met, recent blooms of macroalgae and subsequent seagrass declines in sections of Chincoteague Bay due to smothering by macroalage point to serious issues compromising the continued expansion. Seagrasses are all but absent in all other coastal bays of Virginia but recent transplant successes by VIMS scientists in two of the coastal bays in Virginia suggest that water quality is adequate in some coastal bays. Recovery may be aided by restoration efforts in certain sections of these bays not influenced by macroalgae.

Major problems influencing expansion will be from anthropogenically derived nutrients both from runoff and groundwater, perhaps pointing to a scenario noted in Delaware's inland bays. Seagrass loss from clam dredging has been addressed in both states and has become an enforcement issue dealing with a few individuals violating the protected zones.

The return of seagrass to the Coastal Bays over the last 30 years is certainly a significant event not noted in many coastal bays of the mid-Atlantic. Continued persistence and expansion will only occur if the issues surrounding the causes of macroalgal changes are investigated and corrected.

Summary:

Dr. Robert Orth discussed the historical trends in Submerged Aquatic Vegetation (SAV) in the Maryland Coastal Bays as they related to global trends. He began with a brief description of the dispersal mechanisms for the two species of SAV common to the Coastal Bays, Eelgrass (*Zostera marina*) and Widgeon grass (*Ruppia maritima*). He then discussed the wasting disease that caused losses of SAV, in temperate coastal waters worldwide. Dr. Orth described the present trends in SAV coverage in the Maryland coastal bays as increasing over the last decade and attributed this natural recovery to good water quality and adequate seed sources, noting that there was a slight decrease at two areas inthe Coastal Bays in 2000 (figure 4). He concluded

Eelgrass (*Zostera marina*).

with a discussion of the potential threats to SAV in the Coastal Bays (disruption of SAV beds by fishing gear and increased competition with macroalgae as eutrophication increases), and transplanting efforts that can possibly aid in countering losses or reductions in SAV beds.

Widgeon grass (*Ruppia maritima*).

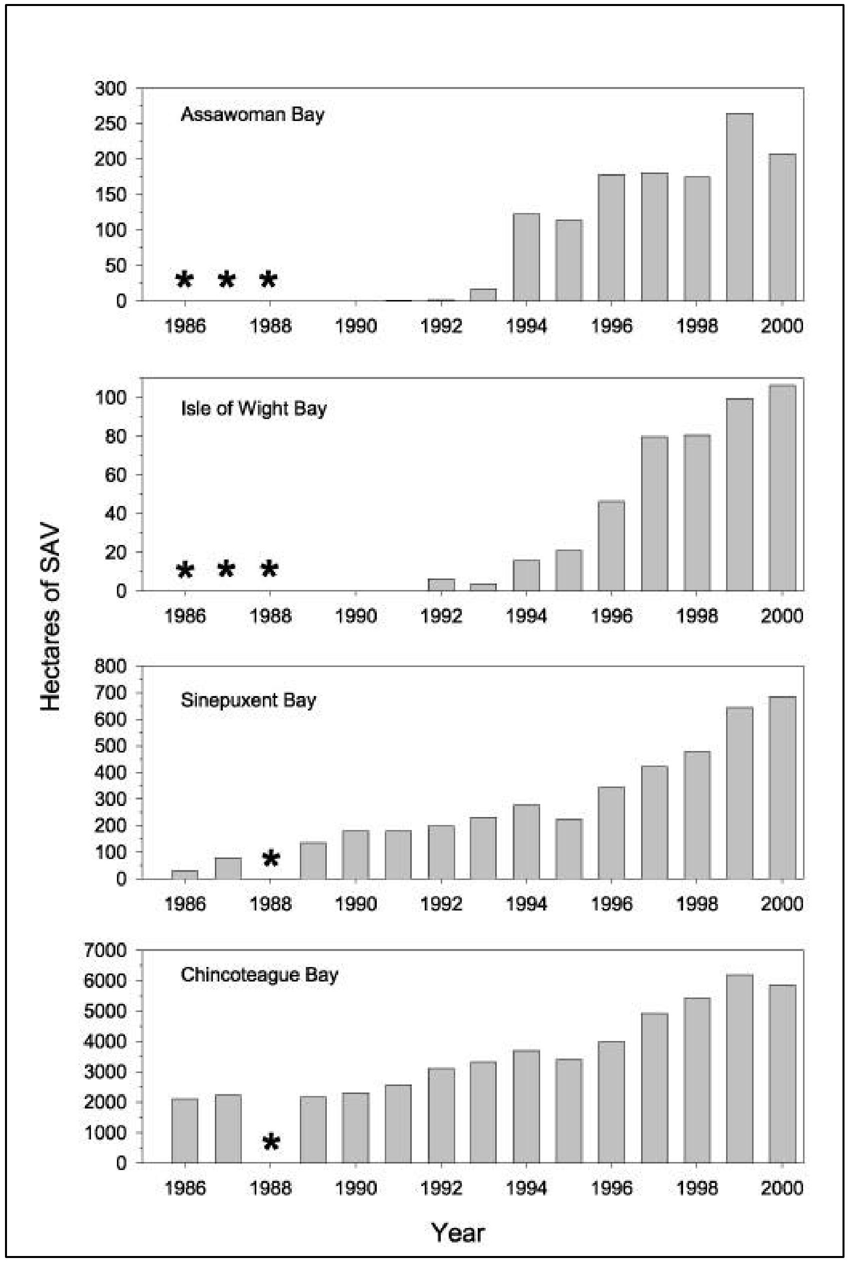


Figure 4. Trends in SAV coverage over time in Maryland coastal bays (* indicates area not sampled).

Selected Refernces:

Orth, R. J., J. Simmons, R. Allaire, V. Carter, L. Hindman, K. Moore and N. Rybicki. 1985. Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Tributaries – 1984. Final Report to U.S. EPA,.Coop. Agreement X-003301-01. 155pp.

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Orth, R. J., A. A. Frisch, J.F. Nowak and K. Moore. 1989. Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Chincoteague Bay – 1987. Final Report To U.S. EPA. 247 pp.

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Orth, R. J., J.F. Nowak, G.F. Anderson, and R.J. Whiting. 1993. Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Tributaries and Chincoteague Bay – 1992. Final Report To U.S. EPA, Chesapeake Bay Program, Annapolis, MD. Grant No. CB003909-01. 268 pp.

Orth, R. J., J.F. Nowak, G.F. Anderson, and R.J. Whiting. 1994. Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Tributaries and Chincoteague Bay – 1993. Final Report To U.S. EPA, Chesapeake Bay Program, Annapolis, MD. Grant No. CB003909-02. 262 pp.

What is Limiting SAV Distribution in Chincoteague Bay?

Evamaria W. Koch, Horn Point Laboratory, University of Maryland Center for Environmental Science, P.O. Box 775, Cambridge, MD 21613

Abstract:
The asymmetric distribution of seagrasses in Chincoteague Bay (mostly on the east side) suggests that habitat conditions in western Chincoteague Bay are limiting. The first habitat requirement that needs to be met is light availability. Present and historical data show that light does not appear to be the limiting factor. Consequently, other parameters such as wave exposure and sediment characteristics were investigated as possible parameters limiting seagrass distribution in Chincoteague Bay. Wave exposure indexes were calculated and sediment and plant characteristics were determined throughout the Bay. The results of correlative and manipulative experiments suggest that sediment compaction is limiting the distribution of eelgrass on the western shore of Chincoteague Bay due to poor seed recruitment into these sediments. In contrast, waves may be contributing to the asymmetric distribution of seagrasses only indirectly via the change in sediment characteristics over time. Therefore, waves may indirectly affect seagrass distribution in Chincoteague Bay via shoreline erosion but sediment characteristics in seagrass habitats seems to be the main parameter limiting seagrass distribution.

Summary:
Dr. Koch presented her research that examined factors potentially limiting SAV colonization in Chincoteague Bay, Maryland. She began with a brief overview of the distribution of SAV in Chincoteague Bay, showing that SAV is predominately present on the Eastern shores of the Bay and sparsely present on the West. Dr. Koch examined available data on SAV distribution and potential limiting factors including propugale availability, wave exposure and light limitation. In comparing stations across Chincoteague Bay, she found that propugales were abundant on both shores of the Bay and that wave exposure was actually greater on the Eastern shore, and thus was not limiting colonization on the Western shore. Dr. Koch did find that differences in light attenuation were probably limiting in deeper waters, but not a likely limitation to most of the bay where depths are generally less than 1.2 m. She then tested Demas' hypothesis that "the low abundance of seagrasses in western Chincoteague is due to the fine and highly organic sediments" and found that, contrary to his conclusions, organic sediments did not appear to limit growth. In her field work, Dr. Koch did observe that the areas deplete of SAV were characterized by hard, compact peat sediments that have been exposed due to erosion processes associated with sea-level rise. In examining the critical friction velocity (CFV), she found that the CFV was high enough in the peat dominated sediments to presumably preclude seed burial (figure 5). She concluded from this work that "sediment compaction seems to play a major role in the distribution of seagrasses in Chincoteague Bay" (Koch et al. in press) but that "sea level rise may be accelerating marsh retreat creating unsuitable seagrass habitats (compacted peat) but also leading to other sediment sources (sand dunes) more suitable for seagrass establishment." She also stated that light availability may also be affecting seagrass distribution, especially in the deeper waters (a secondary effect due to sediment type).

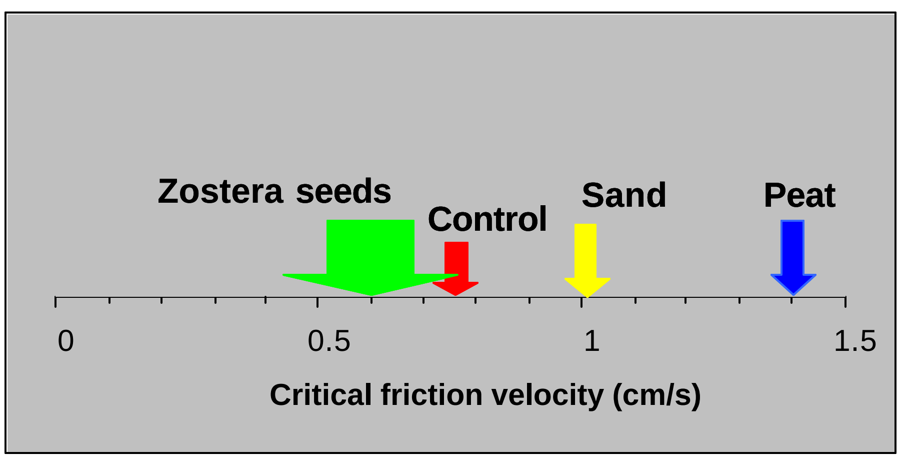

Figure 5. Critical friction velocities for Zostera seeds compared to various

Dr. Koch also reviewed recent trend data in SAV showing that there was a slight drop in coverage in 2000. She showed that the areas showing declines in coverage were also areas where the Maryland Department of Natural Resources (DNR) had observed large volumes of *Chaetomorpha linum.* Dr. Koch reviewed water quality data from the National Park Service to determine if there have been any recent increases in total nitrogen (TN) or total phosphorus (TP) concentrations. These data showed that TN has increased in the last two years in all areas of Chincoteague Bay and Newport Bay (figure 6). Analysis of TP showed slight increases in Newport Bay and two of the three areas of upper Chicoteague Bay over the same time period. She suggested that reduced flushing may be a possible cause for these increased concentrations, and suggested that *Chaetomorpha linum* might be increasing in response to greater nutrient availability.

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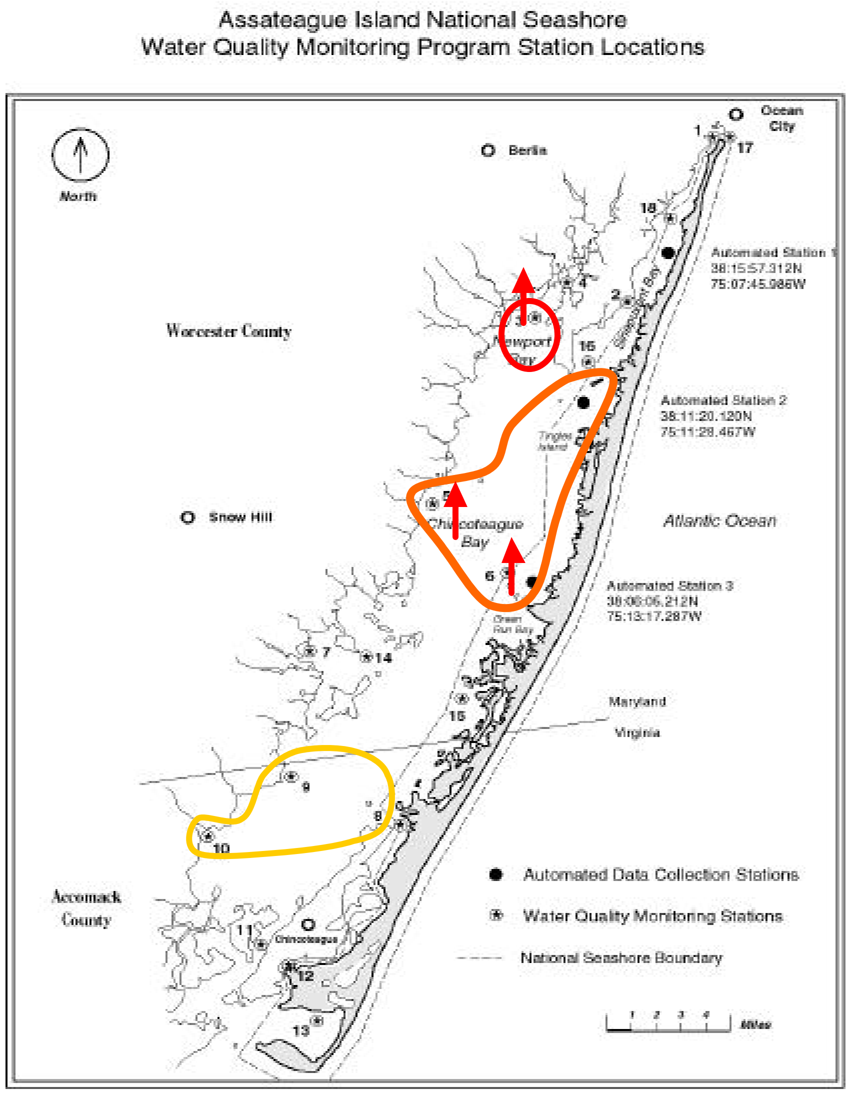

Figure 6. Relative nitrogen concentrations. (red = high, orange = moderate, yellow = low), and trends in phosphorus concentrations (red arrow = increasing concentrations, blue arrow =decreasing concentrations).

Session II

Factors Limiting Distribution and Abundance

Session II included presentations focused on the response of the macroalgae community to eutrophication and how these responses influence the ecosystem. Factors that influence or limit the distribution and biomass of macroalgae in shallow coastal lagoons were explored.

Nutrient Dynamics and Macroalgae Responses

Ivan Valiela, Boston University Marine Program, Marine Biological Laboratory, Woods Hole, MA 02543

Summary:
Dr. Valiela began with a global perspective on the increased occurrence of macroalgal blooms, showing a table of selected examples of the occurrence of seaweed blooms around the world. He noted that other researchers have associated macroalagal blooms with human activity along the coasts, and documented the effects of these blooms. Effects can range from aesthetic impacts to humans (unpleasant odors from macroalagal decomposition), to ecological effects such as altering biogeochemical processes in estuaries, and fostering hypoxic events that can reduce benthic productivity. Dr. Valiela cited several factors that might be contributing to these more prevalent and frequent macroalagal blooms, including decreased grazing by herbivores, increased fecundity and recruitment of macroalgal species, changes in physical conditions of the waterbodies (i.e. flow, light, temperature and salinity), and increased nutrients due to cultural eutrophication (particularly wastewater output). He cited eutrophication as the leading cause of observed increases in macroalgal blooms. In his observations, Valiela found an attendant increase in groundwater nitrate with increased wastewater production, and recommended monitoring groundwater nitrate concentrations as an indicator of eutrophication. Dr. Valiela then showed his work in developing a model of the primary producers' response to increased nitrogen loadings. In his studies, he compared estuaries with varying degrees of groundwater loads and found that the dominant primary producer shifted from SAV to macroalgae to phytoplankton as the nitrogen loads increased.

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Macroalgal Mediation of Nitrogen Cycling in Coastal Lagoons

Karen McGlathery, Department of Environmental Sciences, University of Virginia, Charlottesville, VA.

Abstract:

It is well-known that nutrient over-enrichment of shallow bays can lead to the proliferation of bloom-forming macroalgae. These ephemeral macroalgae are typically filamentous or sheet-like forms (e.g., *Ulva*, *Cladophora*, *Chaetomorpha*, *Gracilaria*) — many are chlorophytes — that accumulate in extensive, thick, unattached mats over seagrasses or the sediment surface. In highly enriched waters, it is not unusual for macroalgal populations to attain peak biomass of over 0.5 kg•m^{-2} and for canopy heights to exceed 0.5 m. These macroalgae often become the dominant benthic autotroph in nutrient-enriched coastal bays, and as such, play a key role in mediating nutrient cycling processes. Because of their position at the sediment-water interface and their ability to store nutrients, macroalgae uncouple benthic-pelagic linkages by intercepting the flux of regenerated nutrients from the sediments to the overlying water column. As a result, water quality often appears high (low chlorophyll, low dissolved nutrients) despite high nutrient loading. Uptake of ammonium and urea by actively growing macroalgal populations prevents release from the sediments to the water column. At the same time, up to 40% of N uptake can 'leak' from the macroalgae as dissolved organic nitrogen. This conversion of bioavailable N to dissolved organic nitrogen may be important in supporting bacterial metabolism in the water column. When macroalgal blooms collapse due to reduced light availability or increased temperatures, organic and inorganic nutrients released to the water column temporarily stimulate phytoplankton and bacterial production. This results in a dynamic switching between benthic and pelagic production in eutrophic shallow waters and accelerated nutrient cycling rates relative to seagrass-dominated systems. In addition, ammonium concentrations are typically elevated within macroalgal mats due to the decomposition of senescent macroalgal tissue deep within the algal canopy where light does not penetrate. These high levels may be toxic to eelgrass, particularly of newly recruiting shoots that exist entirely within the macroalgal canopy.

Summary:

Dr. Karen McGlathery presented a summary of her work in Denmark and Virginia. In examining the fate of nutrient enrichment in Denmark, she found that production shifts periodically between benthic and pelagic production, and therefore, water column chlorophyll *a* is not a reliable measure of eutrophication (figure 7). Macroalgal mats can develop in response to enrichment, and are efficient at taking up and storing nutrients from the water column as well as intercepting nutrient fluxes at the sediment-water interface. Dr. McGlathery also found that depending on light availability, algal mats can intercept but also release ammonia to the water column. Dr. McGlathery showed the importance of residence time on nutrient dynamics and controls on primary production (Valiela et al)., and stated that the nutrient type is also an important factor in controlling primary production. In studies conducted in Hog Island Bay, VA, she addressed the question, "How do macroalgae influence DON cycling?" From this study she concluded that benthic macroalgae community assimilate DON compounds (urea and amino acids), bypassing complete mineralization and they intercept NH4 and urea releases from the sediment, leaking DON compounds to the water column. This process influences water column metabolism, and thus reinforced her earlier findings that water column nutrient and chlorphyll concentrations are not good indicators of eutrophication.

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McGlathery, K.J. 1995. Nutrient and grazing influences on a subtropical seagrass community. Mar. Ecol. Prog. Ser. Vol. 122:239-252.

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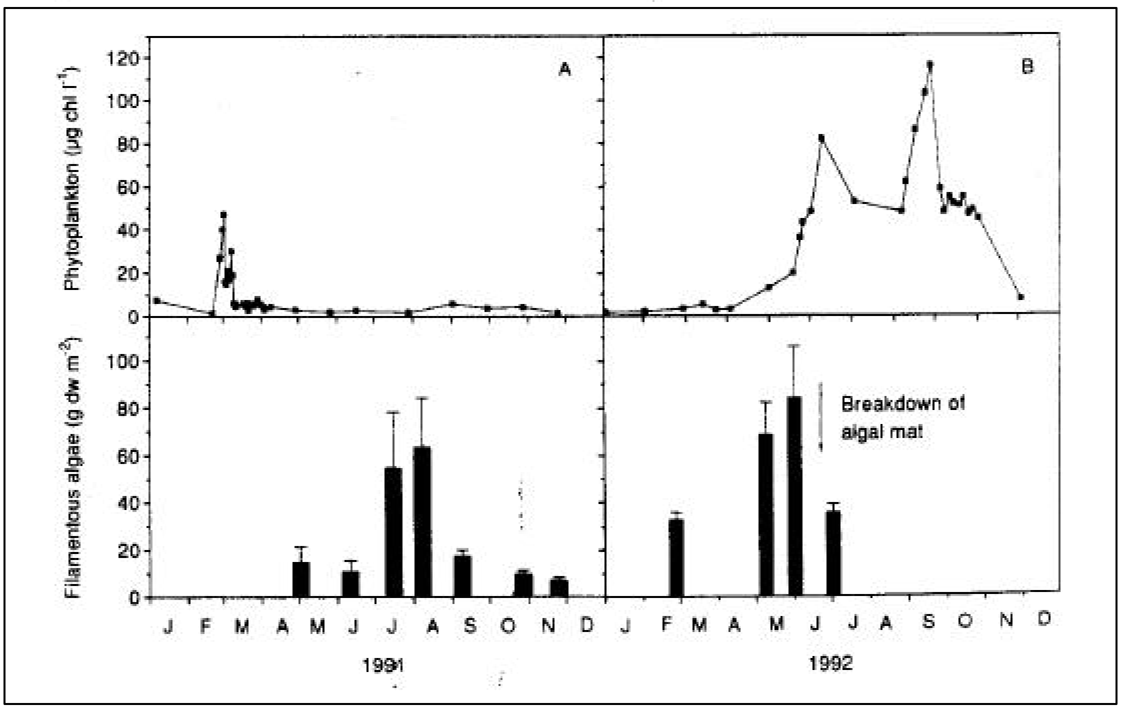

Figure 7. Production of filamentous algae and phytoplankton in 1991 and 1992.

Case Studies: Factors Limiting/Promoting Macroalgae Growth

Dave Goshorn, Maryland Department of Natural Resources, Tidewater Ecosystem Assessment Division, Annapolis, MD 21401

Summary:

Dr. Goshorn presented a summary of limiting factors that influence or control macroalgal growth, including chemical, physical and biological controls (figure 8). His literature review indicated that there was a great range of effects that are species and location dependant. In evaluating nutrient limitations, Dr. Goshorn found that nitrogen to phosphorus ratios were generally lower in algal tissue samples than in the water column. He also found that phosphorus was generally limiting in the spring when light availability and temperatures were low. Under normal conditions, nitrate appeared to be the main control, while ammonia became limiting to macraoalgal growth in low light conditions. Dr. Goshorn also showed that macroalgae have the ability to store excess nitrogen which permits it to grow during periods of limited nutrient availability. Physical factors can also influence macroalgae growth. Salinity and temperature limit the distribution and the growth season of macroalgae. Light can be limiting, especially during times where phytoplankton production is high or when the macroalgal canopy becomes so dense that self-shading becomes a controlling influence. The major biological control that Dr. Goshorn discussed was herbivorous grazing. Several studies evaluated the effects of grazing, and found that grazers can exert considerable pressure on macroalgae, especially in early life history stages and in areas with lower water column nutrient concentrations. Though there are many controls on macroalgal biomass and growth Dr. Goshorn stated the general concensus of the literature cited nutrients as the most important control.

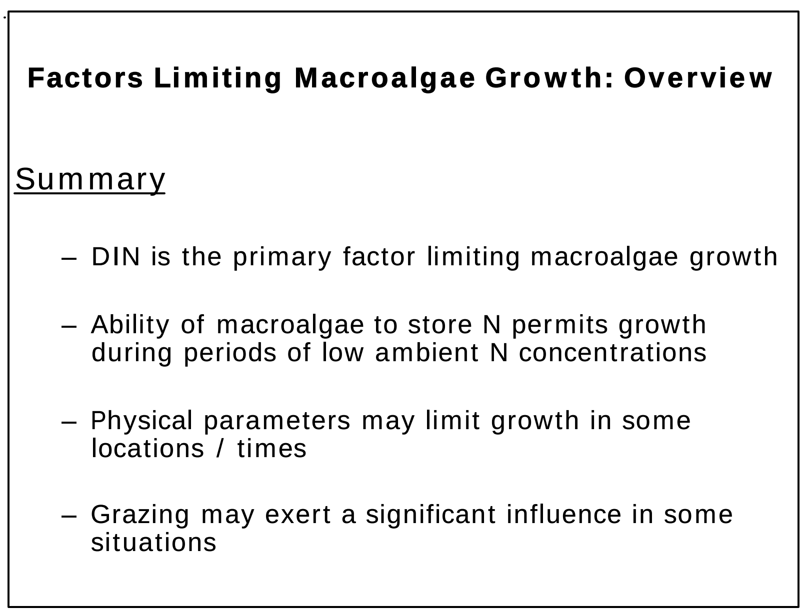

Figure 8. Summary of factors potentially limiting macroalgal growth.

Selected References:

Balducci, C., A.Sfriso, B. Pavoni. 2001. Macrofaunal impact on *Ulva rigida* C. Ag. production and relationship with environmental variables in the lagoon of Venice. Marine Environmental Research 52:27-49.

DeCasabianca, D.-L. and F. Posada. 1998. Effect of environmental parameters on the growth of *Ulva rigida* (Tau Lagoon, France). Botanica Marina Vol 41:157-165.

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Session III

Macroalgae Indicators

The final session of the day examined the potential use of macroalgae as indicators of eutrophication.

The use of Seaweeds as Monitors of Pollutants in Coastal Waters

Howard G. Levine, Dynamac Corporation, Mail Code DYN-3, Kennedy Space Center, FL 32899

Abstract:

Seaweeds have several intrinsic advantages for the monitoring of coastal waters for pollution: (1) They readily accumulate compounds present within their environment. (2) They are sessile and can therefore be used to characterize one location over time. (3) They cannot exhibit avoidance behavior (eg "clamming-up") when pulses of pollutants pass by. (4) They are easily collected in abundance at many sites. Given these inherent characteristics, they can be used as continuous sampling monitors for pollutants. Tissue analyses minimize the difficulties associated with obtaining representative samples of compounds in coastal waters. The degree of pollutant accumulation is a complex function of numerous factors, but if these are understood and taken into consideration when interpreting results, a meaningful comparison of water quality conditions within and between coastal environments is possible.

Summary:

Dr. Levine presented work that he had conducted in evaluating the potential use of macroalgae as bioindicators. He described the structure and life history of *Ulva latuca*, saying that this species' characteristics make it a good candidate for use as a bioindicator. First, because this species is only two cells thick it is "bathed in the aquatic environment" and thus reflects conditions of the water column. It is also easy to cultivate and can be attached to substrate, so it can be deployed at specific locations. In his research looking primarily at metals concentrations in tissue, Dr. Levine found that *Ulva* showed a wide ranged of metals concentrations that were related to ambient concentrations of the water column. The characteristics of *Ulva*, allow for its use as a biological indicator of chemical pollutantants.

Selected References:

Levine, H.G. 1983. Ulva latuca L. as a bioindicator of coastal water quality. Ph.D. Dissertation, Botany Department, University of Massachusetts, Amherst, MA, 235 pgs.

Levine, H.G. 1984. The use of seaweeds for monitoring coastal waters. In: Algae as Ecological Indicators, E. Schubert (Ed), Academic Press, London. Pp 189-210.

Ulva latuca

A Preliminary Assessment of Seagrass Health and Vitality in Assateague National Seashore's Coastal Bays

Stephen Granger, Scott Nixon and Lora Harris, University of Rhode Island, Box 17, South Ferry Road, Narragansett, RI 02882

Abstract:
As part of a study conducted by the North Atlantic Coast Cooperative Ecosystems Studies Unit, researchers at the University of Rhode Island were invited to conduct an assessment of seagrass health in the shallow coastal embayments of Assateague National Seashore. Five stations were selected along the longitudinal axis of Chincoteague Bay and located in seagrass beds near long-term water quality monitoring stations. A number of diagnostic indices, that we developed during previous mesocosm experiments as useful indicators of seagrass health and bed vitality, were measured at each station during May and June 2001. Indices included plant leaf initiation rates (plastochrone interval), measures of above and below ground biomass, production of lateral shoots, and shoot density. In addition, dissolved inorganic nitrogen collected from several small streams entering Newport and Chincoteague Bays and in sewage treatment plant effluent (Assateague Park Services) was analyzed for the abundance of the stable isotope δN^{15}. Tissue samples of seagrass collected at the five stations and macroalgae samples collected near the southern end of Chincoteague Bay were also analyzed for the abundance of δN^{15}. A preliminary review of the data suggest that seagrass beds at Sinepuxent Marker 25 and Coards Marsh displayed the most vigorous growth followed by Horntown Point, while beds at Spence Cove and Tingles Island took longer to produce new leaves and generated fewer lateral shoots. The abundance of δN^{15} was greatest in seagrass leaf tissue taken at Horntown Point and Sinepuxet Marker 25 while plants collected at Coards Marsh, Spence Cove and Tingles Island were similar and lower in δN^{15} concentrations. Seaweed samples had δN^{15} (δN^{15}=7.0 to 8.1) tissue concentrations similar to seagrass samples taken at the nearby Horntown Point station.

Summary:
Mr. Granger described the work that they conducted in Chincoteague Bay to determine the source and fate of nitrogen, using stable isotope tracking. They gathered water samples from several sources in the Chincoteague watershed and analyzed the dN^{15} concentrations (figure 9). They then collected SAV and macroalgal samples from several areas of Chincoteague Bay and analyzed dN^{15} concentrations in theses plant tissues. By comparing the abundance of dN^{15} between the plants and the sources, they were able to associate plant nitrogen concentrations with the nitrogen source. They are in the process of analyzing the data to determine the utility of this tool in the Maryland Coastal Bays, and are hoping to do additional sampling to refine the technology and determine areas within the bays that might be susceptible to anthropogenic nutrient enrichment.

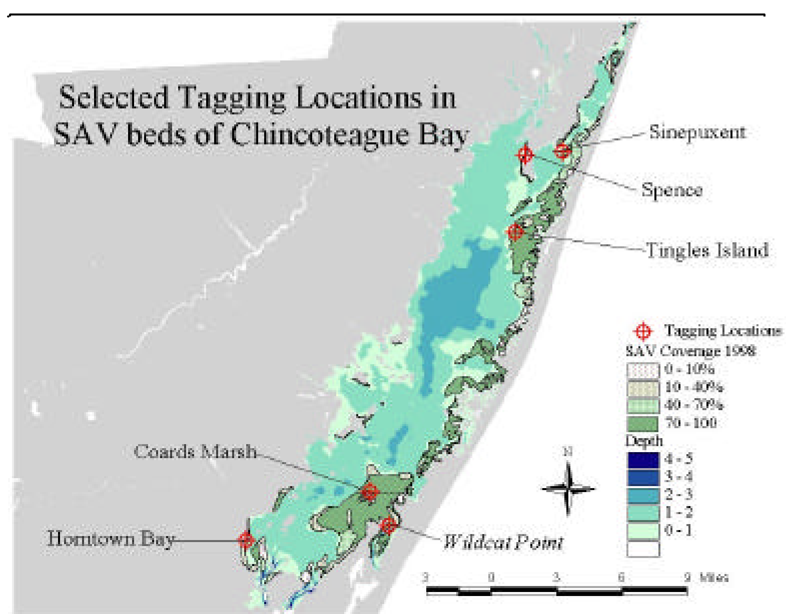


Figure 9. Delta 15 signals from streams, eelgrass and macroalgae in Maryland and Virgina Coastal Bays.

The Relationship Between Water Quality Parameters and Benthic Macroalgal Abundances: Can Macroalgae Be Used as Bio-Indicators of Estuarine Water Quality?

L.M. Valdes & K.S. Price. College of Marine Studies, University of Delaware, Lewes, DE.

Abstract:

Unlike many shallow estuaries along the East Coast of the United States, seagrasses in the Delaware Inland Bays (Rehoboth, Indian River, and Little Assawoman Bays) have been completely replaced as the dominant primary producer by benthic macroalgae and phytoplankton through competition for increased nutrients and decreased light levels. In particular, benthic macroalgal blooms of *Ulva lactuca*, *Gracilaria sp.*, and *Agardhiella tenera*, have become a problem for residents, tourism, and especially for the health of the estuary due to the resulting hypoxic/anoxic conditions associated with macroalgal bloom decline. In order to determine the extent to which water quality parameters are associated with the proliferation of benthic macroalgae in the Delaware Inland Bays, simultaneous measurements of dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), Chlorophyll *a* (Chl *a*), and benthic macroalgal volumes were performed monthly during April through September 1998. Comparisons of DIP, DIN, and Chl *a* concentrations to benthic macroalgal abundances indicate a direct relationship between the dominance of benthic macroalgae and DIP concentrations in areas where phytoplankton biomass is low, and an inverse relationship between the dominance of benthic macroalgae and DIN and Chl *a* concentrations. Elevated levels of DIN in these bays resulted in the dominance of phytoplankton, which in turn, indirectly controlled the abundance of macroalgae through competition for nutrients and shading effects. Therefore, dominance of benthic macroalgae may be indicative of high DIP, low DIN, and low Chl *a* concentrations

Summary:

Ms. Valdes presented work that was conducted in the Delaware and Maryland coastal embayments. This work examined relationships between water quality parameters and benthic macroalgal abundance data from 1998. Results suggest that there is a north to south gradient of macroalgal abundance where the northern bays show higher abundances than the southern areas (figure10). Coinciding with this apparent spatial trend was a decrease in both dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) from the northernmost bays studied. Ms. Valdez suggested that DIN and DIP may be useful indicators of macroalgae in coastal habitats and stressed the importance of competition between macroalgae and phytoplankton for nutrients and light, as an additional factor regulating the abundance of macroalgae.

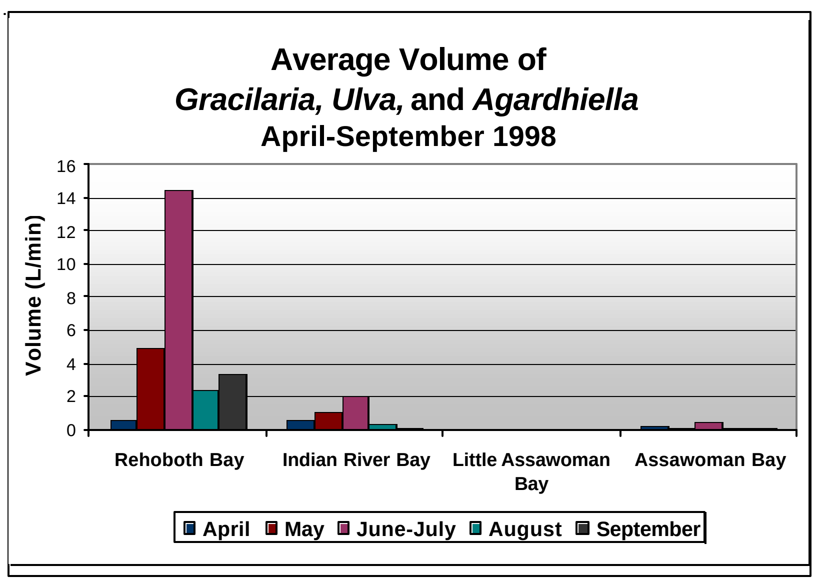
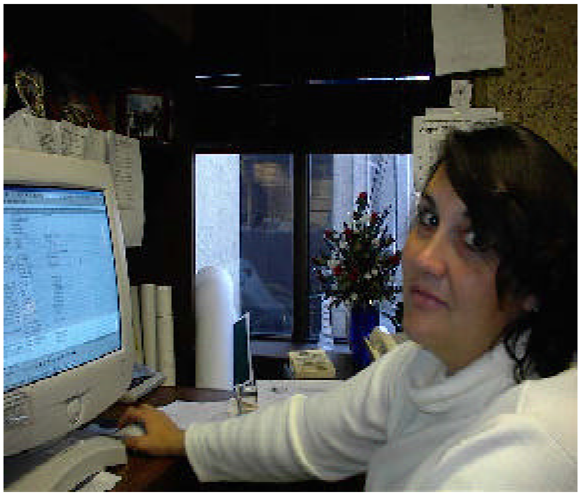


Figure 10. Mean volume of macroalgae found in Delaware coastal bays.

Abandance and Distribution of Macroalage in Maryland Coastal Bays

Margaret McGinty, Carrie Kennedy, Kara Schwenke, Calvin Jordan, Cathy Wazniak, Linda Hanna, Paul Smail, and Dave Goshorn, Maryland Department of Natural Resources, Annapolis, MD



Abstract:

Macroalgal blooms have recently become the focus of monitoring and research efforts in the Maryland Coastal Bays. These blooms are increasing on a global scale in response to nutrient enrichment to shallow coastal waters. Though no historic data exist to ascertain trends in the macroalgal community in the Maryland Bays, anecdotal data suggest that these blooms may be on the increase. This has raised concern over the potential impacts that macroalgal dominance may have on altering aquatic habitat quality.

In 1998 and 1999, the Maryland Department of Natural Resources (DNR) with the University of Delaware conducted a study to examine the response of macroalgae to a nutrient gradient. The study tested the hypothesis that macroalgal biomass increases in response to increased nutrient concentrations. Water quality and macroalgae data were gathered over the two-year study period. Examination of the water quality data showed that there were few differences in nutrient concentrations among embayments. There were, however, differences in macroalgae genera distribution and abundance among embayments. Several of the genera observed have been associated with nitrogen enrichment in other areas of the world. These results led DNR to conduct an extensive mapping exercise in the Coastal Bays. Over 600 sites in the bays were sampled in the spring, summer and fall of 2001. These data have been useful in evaluating the distribution of the prevalent genera of macroalgae, and how the distributions change seasonally. This information is being used to direct development of a monitoring program in the Maryland Coastal Bays.

Summary:

Ms. McGinty presented an overview of the macroalgal monitoring that has been conducted in the Maryland Coastal Bays. Maryland DNR was invited by University of Delaware to participate in a joint study aimed at defining the relationship between water column nutrient concentrations and macroalgal abundance. The goal of the project was to determine whether macroalgae were adequate indicators of coastal eutrophication. DNR monitored over 200 stations in the Maryland portion of the Delmarva Bays between 1998 and 1999. Parameters measured at each station included nutrient concentrations, water column physicochemical parameters and total macroalgal volume by species. These data were examined using correlation matrices to determine if there were any potential relationships between water quality parameters and macroalagal abundance. Of the parameters measured, total nitrogen (TN) correlated most strongly with macroalagal volume (figure 11). Twenty-six genera were observed over the two years of sampling. Of the three general classes of macroalgae, Rhodophytes (red algae) were dominant. Several genera that have been associated with nutrient enriched conditions were observed in abundance in localized areas of the Maryland Coastal Bays. *Agardhiella spp*. and *Gracilaria spp*. were prevalent in the northern bays and *Chaetomorpha spp*. in the southern bays. This study revealed that the macroalagal community was more abundant and widespread than previously realized.

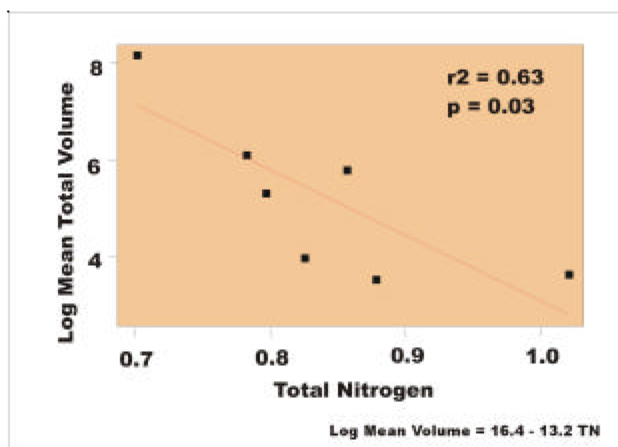


Figure 11. Total nitrogen vs. the mean total volume of macroalgae.

After evaluating these data, the decision was made to map the macroalgal community in the Coastal Bays using a grid sampling approach. Over 600 stations in Maryland were sampled in the spring, summer and fall of 2001. (A winter sampling will also be conducted in early March 2002.) These data allowed us to map the overall distribution of macroalgae by season and revealed those areas of the coastal bays that have persistent macroalgal communities (figure 12). These data will be examined to direct future monitoring of the macroalage in the Maryland coastal bays.

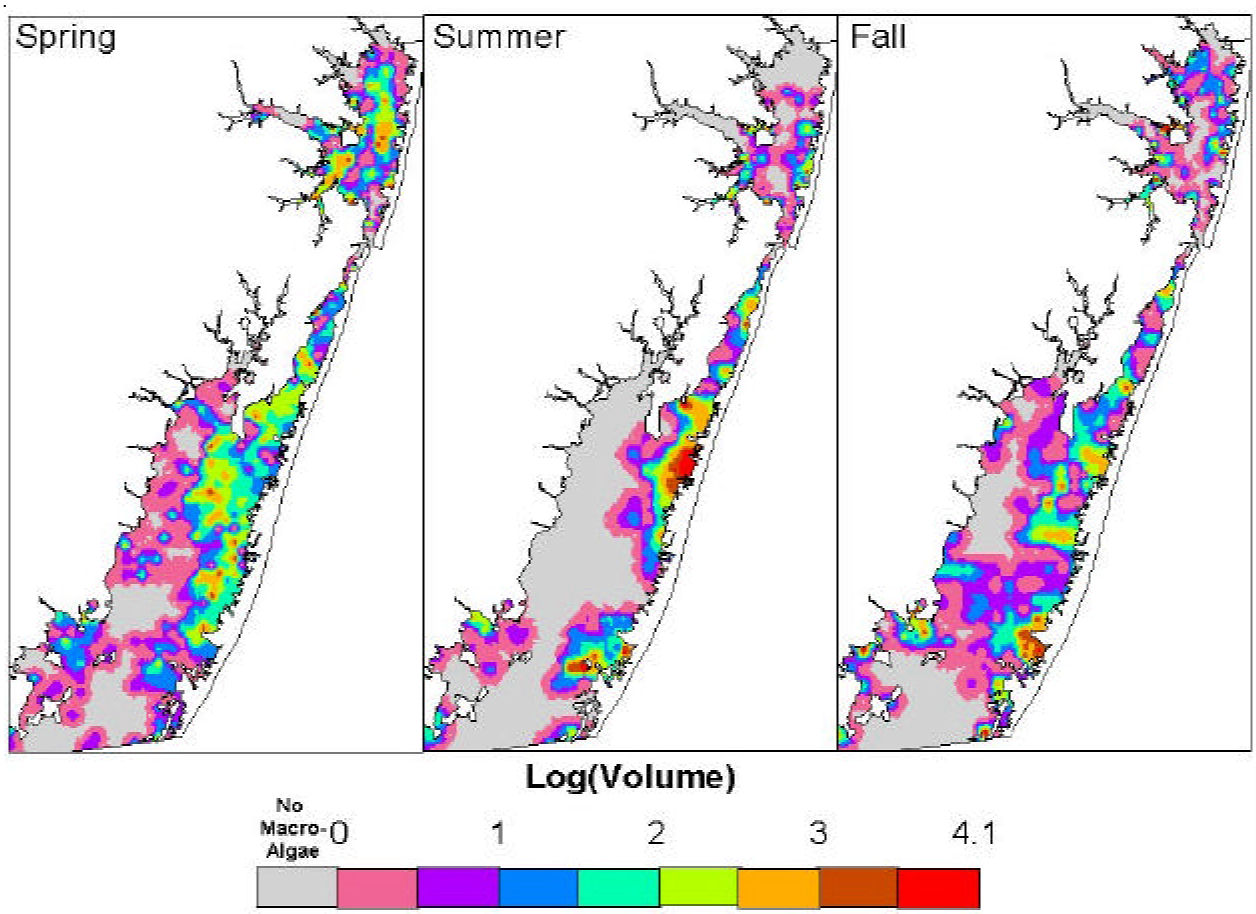


Figure 12. Interpolation of the total volume of macroalgae in Maryland Coastal Bays, for each season sampled.

Session IV
Monitoring Methods for Aquatic Vegetation

This session included presentations on various monitoring methods that have been employed to assess the distribution and abundance of macroalgae.

Macroalgae Monitoring in Rehoboth Bay

Kim Cole, Delaware Coastal Programs, Division of Soil and Water Conservation, Department of Natural Resources and Environmental Control, Dover, DE

Abstract:

Every year more boaters, fishers, and other recreational users place a larger strain on the limited space and natural resources of Rehoboth Bay. Regional development, agricultural, and industrial activities also impact the Bay with increased runoff of chemicals and nutrients. A particular genus of macroalgae, *Ulva* (Sea Lettuce), grows in these waters naturally, but due to changing water chemistry is growing out of control. Large increases in *Ulva* can lead to an increase in dead organic matter and to reduced dissolved oxygen levels in the Bay. Lower dissolved oxygen can have a significant impact on the local aquatic ecology. Increased dead organic loads floating in the Bay can also cause foul odors and create hazards for boats.

Government agencies have funded *Ulva* collection operations to reduce the impacts of the macroalgae on the ecosystem and recreational opportunities in Rehoboth Bay. However, the impacts of *Ulva* harvesting operations on other living resources have not been well quantified. Few data exist on the spatial extent of *Ulva* in Rehoboth Bay or the effectiveness of the collection operations. It seems imperative that the agencies funding the operations identify the present extent of *Ulva* in the Bay and periodically update that information to determine the effectiveness of their efforts.

The Delaware Coastal Programs (DCP) first attempted to identify the spatial extent of macroalgae, including *Ulva*, in Rehoboth Bay in the late Spring of 1999. DCP utilized aerial photography, ERDAS Imagine image processing software, a Geographic Information System (GIS), and a limited field survey from Delaware's Department of Natural Resources and Environmental Control's Division of Water Resources to do this work. The project resulted in the spatial identification of macroalgae, including *Ulva,* in all but the deepest parts of the Bay. Although anecdotal evidence suggests macroalgae in the center of the bay, the images could not verify macroalgae presence in that area.

In an attempt to map those areas too deep for aerial photography, the Delaware Coastal Programs staff in cooperation with staff from NOAA's Coastal Services Center mapped the entire Rehoboth Bay by using a GPS controlled, shallow water hydro-acoustic sensor RoxAnn Seabed Classification System. RoxAnn classifies bottom type by extracting data on bottom roughness and bottom hardness from sounder echos. It operates at shallow depths and displays data in real-time as a geo-referenced color display on a shipboard computer. Data on time, position, depth, and classification parameters are logged at 1 second intervals to a computer file which can be used to export data to a geographic information system (GIS) for post-processing. GIS analysis is used to determine the seabed boundaries and areas to measure and display differences between successive surveys.

Ulva latuca accumulation near-shore in Delaware.

Summary:

Ms. Cole gave an overview of the purpose and approach to monitoring macroalgae in Delaware's coastal bays. She described some of the key management issues in the coastal bays, identifying prolific *Ulva latuca* as a main concern to citizens, due to the unpleasant odors associated with its decomposition process. This concern prompted a seaweed harvest program in Delaware, to remove *Ulva* from the Bays.

Ms. Cole then described two methods used to map macroalgae in Rehoboth Bay, Delaware, traditional aerial photography and relatively new acoustic sampling technology, the RoxAnn Seabed Classification System, which is used to map benthic habitat (bottom type and depth). She also explained the process followed to apply the two methods to map macroalgae. She stated that this technology is now being incorporated into the state's monitoring, and has met the objectives established for this monitoring approach.

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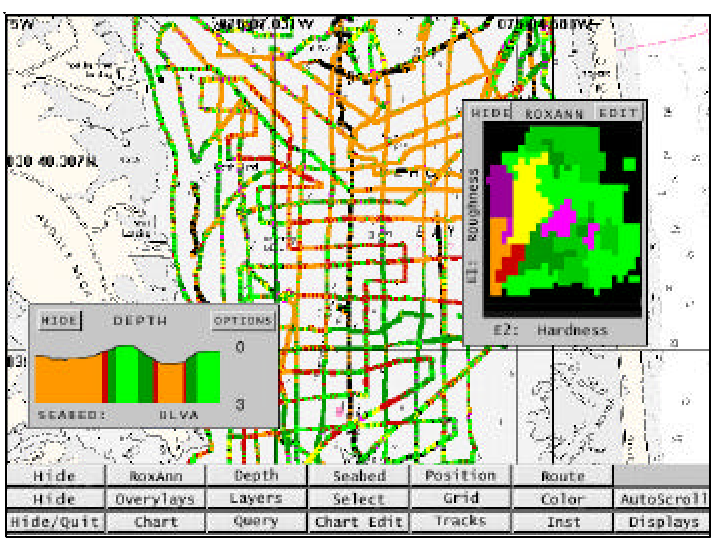
U.S. NOAA Coastal Services Center. 2001. Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach by Mark Finkbeiner [and by] Bill Stevenson and Renee Seaman, Technology Planning and Management Corporation, Charleston, SC. (NOAA/CSC/20117-PUB). Available on: U.S. National Oceanic and Atmospheric Administration. Coastal Services Center. Submerged Aquatic Vegetation: Data Development and Applied Uses. (CD-ROM). (NOAA/CSC/20116-CD). Charleston, SC. 2001.

The mechanical harvester used to gather Ulva in Delaware.



Sample of RoxMap software in the field.

Historical and Current observations on macroalgae in the Hillsborough Bay Estuary (Tampa Bay),Florida

J.O.R Johansson, Bay Study Group, City of Tampa, Tampa FL.

Abstract:

Complaints from residents of Tampa in the early 1960s about obnoxious odors from decaying macroalgae along the western shore of Hillsborough Bay initiated an early study to control estuarine eutrophication. Results from the study, published in 1969, linked the build-up of macroalgae along the shore, and poor bay water quality, to wastewater discharges with high nutrient and organic content. The City of Tampa's wastewater plant and the Central Florida fertilizer industry were identified as the two major sources of nutrient pollution to the bay. The study concluded that large reductions of nutrient discharges, specifically of nitrogen, were needed from these sources to improve water quality and to restore a diverse bay ecosystem. Local and state regulations, primarily aimed at reducing point-source nutrient pollution, resulted in large reductions of phosphate and nitrogen discharges to the bay during the 1970s and the early 1980s. By the mid 1980s, Hillsborough Bay showed signs of lessened eutrophication, including a near 50 percent decrease in phytoplankton biomass and new growth of submerged seagrass. Macroalgae biomass, in contrast, remained high and odor complaints were still being received by the City of Tampa in the early 1980s. In 1983, the city contracted for a year-long study of macroalgae biomass and distribution in the bay. This study found areas with much higher biomass than that reported in 1969; however, attempts to link macroalgae biomass to bay water quality and other potentially important variables were inconclusive. To improve the understanding of macroalgae dynamics in Hillsborough Bay, the City of Tampa soon thereafter initiated an in-house long-term macroalgae monitoring program, that since 1986 has provided monthly biomass and species composition information from five fixed transects. In addition to the transect monitoring, low level aerial observations, conducted on a near monthly schedule, have been used to estimate bay-wide macroalgae coverage. Results from this study indicate that the annual bay-wide macroalgae coverage has decreased farily steadily from about 300 ha in the late 1980s to less than 30 ha since 1997. Estimated average monthly biomass has decreased from a peak of near 150 tons wet weight in 1988 to less than 1 ton wet weight since 1997. *Gracilaria spp.* have often dominated both in terms of biomass and frequency of occurrence during the 15 year monitoring period. Other major species include: *Spyridia filamentosa, Ulva lactuca, Agardhiella tenera*, and the attached alga *Caulerpa prolifera*. Long-term trends in Hillsborough Bay macroalgae biomass and coverage prior to 1986 are difficult to determine due to differences in sampling procedures between studies. Recent maximum biomass may have occurred during the early and mid-1980s, which coincides with a period of very low seagrass coverage as indicated by historical aerial photography. Unquestionably, the recent increase in Hillsborough Bay seagrass coverage has coincided with a substantial decrease in both phytoplankton and macroalgae biomass. These changes suggest that conceptual estuarine eutrophication models, which have been used to relate seagrass loss to increased phytoplankton and macroalgae biomass, also may be used to describe ecological improvements associated with reduced eutrophication.

Summary:

Mr. Johansson described the monitoring approach applied in Hillsborough Bay to track the effect of reducing point source loads to the bay. In giving an overview of the issue, Mr. Johansson described the condition in the late 50's, early 60's. Hillsborough Bay had experienced a decline in SAV with an attendant increase in macroalgae. As the macroalgal community became more prevalent, it became a public concern. Algae would die, accumulate in shore and emit noxious odors as they decayed. When the problem was investigated, researchers concluded that nutrients from waste-water and fertilizers were the problem. They began to manage these sources to reduce loads and tracked the biomass and distribution of macroalgae and SAV to determine if this approach was effective in restoring SAV. Aerial surveys by helicopter or small plane recorded vegetative coverage, coincident with ground surveys where macroalgae were collected using an otter trawl. In addition, water samples were collected to evaluate chlorophyll *a* concentrations. Figure 11 shows trends from this sampling approach. The data showed that as nutrient loads were reduced, declines in macroalgae and chlorophyll *a*

concentrations were noted with a concurrent increase in SAV coverage.

Mr. Johansson also evaluated the macroalagal aerial and ground surveys to determine how well they compared. In their analysis, they found that there was a strong relationship between macroalgal biomass estimated from the trawl surveys and the macroalgal coverage estimated from the aerial survey (figure 12).

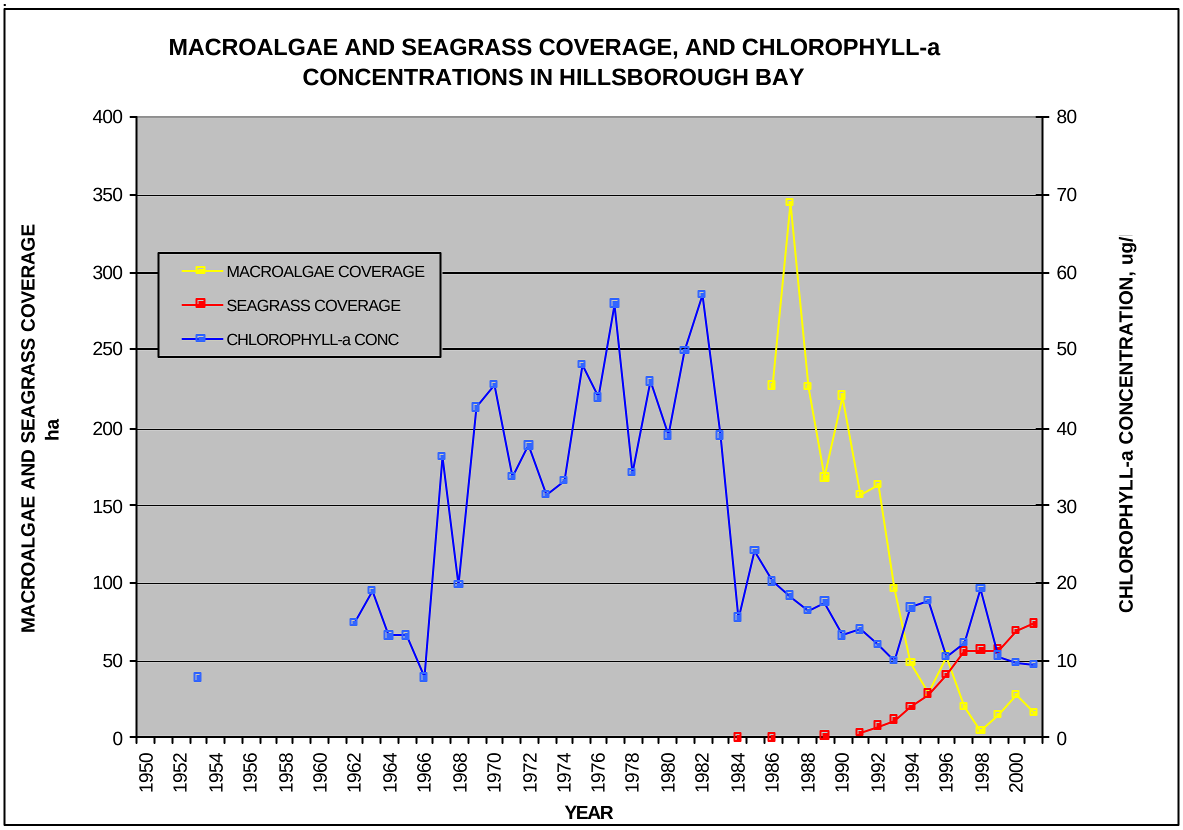


Figure 13. Macroalgae, seagrass coverage and chlorophyll a concentrations in Hillborough Bay, Florida.

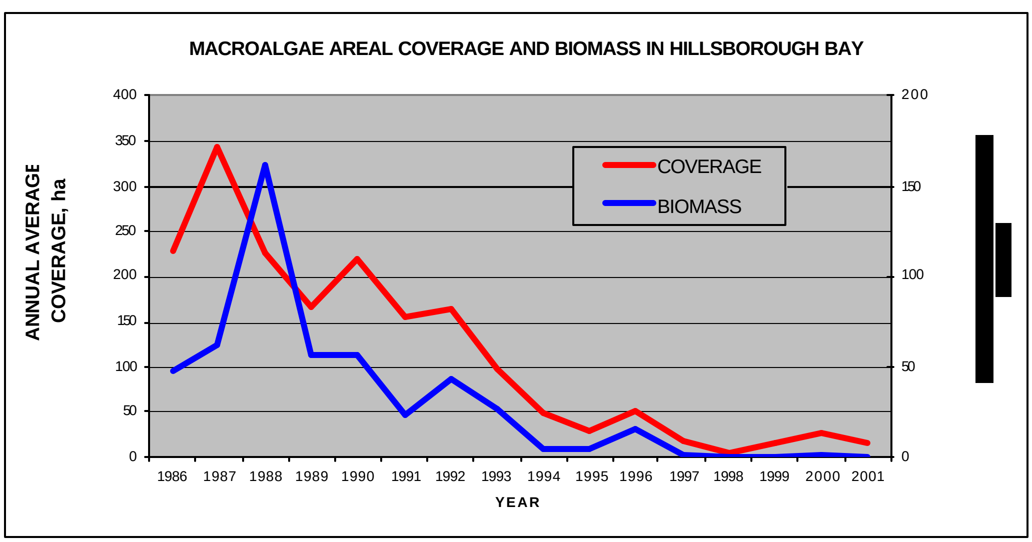


Figure 14. Macroalgal aerial coverage and biomass, over time in Hillsborough Bay, Florida.

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Avery, W. 1997. Distribution and abundance of macroalgae and seagrass in Hillsborough Bay, Florida, from 1986 to 1995. In Proceedings, Tampa Bay Area Scientific Information Symposium 3, S.F. Treat (Ed), pp 151-165.

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Using Low Level Aerial Photography to Assess Macroalgae Distribution

Tom Parham, Maryland Department of Natural Resources, Annapolis, MD

Abstract:

Low level aerial photography was examined as an alternative to field sampling for determining macroalgae spatial distribution in Maryland's Coastal Bays. Low level, color photographs were taken shortly after the 2001 Spring and Fall macroalgae field sampling to determine whether macroalgae could be assessed in areas with and without submerged aquatic vegetation (SAV). Preliminary results indicate that this type of photography can be useful in assessing distributions in shallow water areas without extensive SAV beds. In some instances, individual species can be identified in areas with large, monotypic mats of macroalgae. While this type of monitoring is expensive, modifications in altitude and film type could reduce overall cost.

Summary:

Mr. Parham presented an overview of low-level aerial photography that was conducted in the coastal bays to determine the utility of this tool in tracking macroalgal coverage. The photographs were acquired within a two-week window of the macroalgae sampling and will be compared to these data when the photographs are fully digitized. Several areas were ground-truthed using the photo images to determine how well these images captured the distribution of SAV. Preliminary evaluation suggests that where there is dominance of macroalgae, the photos do a good job of representing macroalgal coverage. However, where there is mixed vegetation, it is difficult to discern various vegetative types.

Macroaglae Monitoring Methods

Cathy Wazniak, Maryland Department of Natural Resources, Annapolis, MD.

Summary:
Mrs. Wazniak presented a list of monitoring methods used in the field for both coverage and biomass that have been reviewed by the Maryland Department of Natural Resources. While some of these methods are adequate for research projects or small scale surveys, many are not adaptable for a large scale community assessment. Problems were inherent in most design options since macroalgae biomass may be attached at the bottom or accumulated in unattached mats. Considering these challenges in the context of our monitoring objectives, several questions need to be considered: What should be the standard method to sample? How should it be reported: biomass, wet weight, dry weight, total volume? Will shoreline surveys that determine trends effectively capture the community dynamics, or are there too many factors (i.e. wind, shoreline accessibility, difficulty in differentiating macroalgae from SAV wrack) that influence natural variation and sampling error?

Noting that many designs miss the shallow habitat and shoreline structures, Mrs. Wazniak reviewed a comprehensive list of approaches that have been used to sample macroalgae in all types of habitat. The following list shows the reviewed approaches according to the sampling objective:

Sampling designs that have been adopted for macroalgae studies include:
- grid sampling
- random (quadrant sampling)
- transects (trawl or scuba)
- enclosure/ exclosures
- mesocosms and microcosms
- C:N:P ratios

Methods that have been applied to assess vegetative coverage include:
- Aerial Survey
  - grid
  - hyperspectral/ multi
  - photography - LIDAR (problematic when mixed with SAV)
  - Remote Sensing (RoxAnne)
- Box corer (macrophyte sampler designed by ACOE) / Pole core
- Crab scrape (suggested)
- Dredges
  - sled dredge (used by Del)
  - 'Lucky'hand dredge (designed by VIMS and used by MD)
  - hydraulic clam dredge
- Transects
- Trawl (otter, hand)
- Oyster tongs (suggested)
- Quadrants
  - scuba
  - dip nets
  - suction hose

Biomass methods that have been used incldue:
- canopy height
- mat thickness
- quadrant

scuba
drift nets
pop nets
modified box core (hydraulic smapler)
suction sampler
modified box corer (hydraulic)
throw trap, then cleared with dip net
shoreline walks

These methods were presented to the group as a whole, and were considered in the Sampling Methods break out group.

Session V

Break Out Sessions

The break out groups were asked to discuss various topics related to developing a plan to monitor macroalgae. The goals of the monitoring were to focus on evaluating status and trends to determine if the macroalgal community is changing in response to management activities in the Maryland coastal bays.

Group 1: Sampling Methods and Measurement Parameters

What is the best sampling approach to assess status? To assess trends? Is there one approach that will allow assessment of both status and trends under one program?
What is the best gear for these approaches?
What are the appropriate temporal and spatial scales for assessing status and trends?
Is it necessary/appropriate to sample the entire community or are there several single species that could be sampled more efficiently and yield the same information?
What other parameters are necessary to measure in order to understand the control mechanisms?

Discussion:
Dr. Goshorn lead the group discussion concerning sampling methodology. The first item taddressed was the species to monitor. The group thought it was necessary to focus on more than one species, however, they felt that it was not necessary to exhaustively monitor all species, as long as status and trends were determined for the most dominant species. The group also recommended that DNR find a way (possibly using volunteer monitors) to monitor hard substrate to determine if this is potentially the source of macroalgae for the coastal bays and to survey for additional species. They also considered the necessary frequency and intensity of sampling. It was suggested that a power analysis be conducted on the existing data to determine the optimum sample intensity. The timing and frequency of sampling would depend on the objectives of the sampling.

The group then discussed gear selection and reviewed the advantages and disadvantages of each gear type summarized in Mrs. Wazniak's talk. The group felt that aerial photography would be the most comprehensive approach; however the technology needs to be refined for application in the coastal bays where seagrasses and macroalgae may be confused. Groundtruthing would be necessary to obtain complete species composition. Low level vertical aerial photography would be difficult in this area as well because of the difficulty differentiating SAV and macroalgae and the fact that a large number of reference marker floats would be needed. Remote sensing (hyperspectral) approaches would be most useful but technology needs to be further tested for this type of application (NOAA is testing an instrument in Tampa Bay that may be able to ID macroalgae species). Underwater video or photography might be useful to help ground truth aerial images for species presence/absence. Oyster tongs were suggested to be an effective sampling gear for all water depths; however, they are difficult to use and gear efficiency needs to be tested. The comment was made that gear efficiency should be tested for several gears and the most efficient gear for meeting the objectives should be selected.

The group finished with a discussion concerning estimating biomass. The group strongly suggested that DNR determine the collection efficiency of the hand dredge that is being used for surveys (potentially different in different genera or densities of algae and at various depths). The current method does not collect all floating algae (material moves around along the bottom but some does drift). The group wondered if it would take that much more time to use the throw trap in lieu of the dredge to ensure comparable, quantitative measurements. Several participants recommended that DNR develop a wet to dry weight conversion so that biomass estimates could be derived. It was also suggested that tissue nutrient concentrations be developed for the dominant species so that mass balances could eventually be calculated.

Recommended Actions:
1. Perform gear efficiency and choose best gear to meet monitoring objectives.
2. Create a voucher collection for reference.

3. Conduct power analysis to determine number of stations
4. Consider a two part monitoring program: aerial surveys for coverage and groundtruthing for biomass estimates in problem areas.
5. Standardize/develop volume/weight measurements in field to biomass measures in lab.
6. Measure tissue composition for N and P for use in mass balance.

Group 2: Research Needs

What information is needed, but not presently available in order to better understand the influence of macroalage on the ecosystem, and therefore better monitor the community? What are the specific research needs?

Discussion:
Sellner briefed the conference participants on the discussion concerning research needs. The group focused on short term research needs that would be helpful in designing a monitoring program including analytical approaches using available data (developing empirical relations), determining the sources of macroalgae in the bays and the fate of the algae in the ecosystem (possible relation to low dissolved oxygen areas or blooms of HABs).

A high priority was immediately identified in the discussion, to explore the existing data to begin to identify important questions and guide future research. It was recommended that winter nitrates should be evaluated for trends. Some additional analyses discussed included: 1) using salinity (crude water balance) and temperature (or thermal imagery) data to help identify areas of direct groundwater upwelling of nutrients to the bays, 2) analyzing nutrients verses salinity (conservative tracer), 3) analyzing wind frequency and tidal distribution of algae (e.g., hydrodynamic model) and 4) analyzing temperature changes to determine if increased bay temperatures could have provided a more optimal habitat for some of the southern genera of macroalgae. Another suggestion was to reverse the question and determine if there have been any fisheries changes due to the changes in habitat (e.g., vegetation), although it was suggested by a local fisheries biologist that the fish are pretty resistant and the data have not shown any changes (except maybe an increase in flat fish in Chincoteague Bay).

It was also suggested that the identification of the sources of the algae would be beneficial; a cursory survey of solid surfaces (e.g., piers and bulkheads) to find 'seed'-producing algae, using radium dotters to trace the nutrient sources (NO_3= allocthonous; NH_4=regeneration). Biomass estimates and tissue nutrient concentration would also help in determining mass balance of nutrients for the bays.

To help determine the fate of macroalgae in the coastal bays, collaborative activities should be explored with university researchers investigating harmful algal blooms in on-going projects. Additionally, macroalgae biomass in seagrass beds should be examined to determine impacts to this important habitat (e.g., need canopy height to related to light penetration).   Although insuffiecient time limited extensive discussion, other important areas to investigate include succession between macroalgae species and determining whether macroalgae blooms lead to phytoplankton blooms, SAV or are exported from the systems.

Summary of Research Needs:
The questions driving research were identified as: 1) why are macroalgae proliferating now? 2) what controls macroalgae blooms? 3) can the increase in macroalgae be reversed? 4) what is fate of the macroalgal biomass? These questions lead to the following research priorities:

1. Explore and analyze existing data first. Examine winter nutrient concentrations for any trends.
2. Identify sources of nitrogen input.
3. Determine number and extent of any 'hot spots' of groundwater influx of nitrogen to the bays directly (thermal imagery).
4. Use isotopes ($ä^{15}N$, radium isotopes in GW) and tissue C:N ratios.
5. Estimate biomass for existing species and compute community stocks.
6. Conduct hard substrate survey (bulkheads, canals, etc).
7. Target sampling of biomass (e.g., canopy height) in seagrass beds to determine if any impact (light stress during critical periods) might be expected.
8. Determine fate of organic and inorganic nutrients derived from macroalgae decomposition, perhaps collaborating with the research teams for the Brown Tide ECOHAB project in VA.

Group 3: Opportunities for Additional Data Analysis

What additional analysis can be done to determine the best monitoring methods? To assess the impacts of macroalgae to the ecosystem? To determine linkages between macroalgae and water quality parameters/other living resources/groundwater? What hypothesis can be formed and tested with the available data? What other data exist that can be brought into these analyses?

Discussion:
Dr. Boynton summarized the discussion of the data analysis break-out group. The main question of focus was, "What can we do with data that we already have?" If we want to explore the enrichment and outbreak link, then it is critical to get the nutrient budget right in order to reduce uncertainty. The group discussed which nutrients and impacts should be further investigated as well as what analyses could be done with the existing data. In discussing the nutrient budgets the group identified several data sets that exist and could be analyzed for loads including water quality data that the State and National Park Service collect, ground water data that the U.S. Geologic Service gathers, and atmospheric data that is available through the National Atmospheric Deposition Program. In addition to defining the nutrient budget, the group discussed other data and analysis needs including understanding ground-water cycles and influences, oxygen dynamics, metals bioaccumulation, the relationship between long term fish-eries changes and vegetation, light field effects and small scale bathymetric influences.

There is a need to determine the relative loadings from surface water and groundwater. Groundwater is a significant source of nitrogen to the coastal bays (based on USGS report) and may be influencing macroalgal abundances. The lag time between application of nutrients on land and the delivery of nutrient loads from groundwater to surface waters may be related to the response time of the macroalgae community. Phosphorus and iron are also significant components of groundwater and are important for macroalgal growth. (*Note:* Iron is the other third most important nutrient for macroalgae). Considering the influence of groundwater nutrients and sediment metals concentrations, more analysis of groundwater (on space specific scales) is needed. The group discussed the δN^{15} methodology as a cost effective method to define nutrient loads and sources. Data that determine loading factors for shore erosion (MGS data for C,S,N and metals) are also needed. The group thought this was particularly important, considering that 10% of the phosphorus load in the Chesapeake Bay is qually derived from rivers and shoreline erosion. The group also discussed the need to determine the fate of particulate phosphorus derived from chicken waste and waterfowl. There was discussion concerning whether these loads were directly deposited to the bays released from waterfowl impoundments. The group also discussed how macroalgae might interrupt the benthic-pelagic cycling of phosphorus. In Rehoboth Bay phosphorus is lost from iron-rich sediments when sediments become anoxic. Do macroalgae intercept these nutrients in these systems?

The group discussed the link between oxygen problems in the bays and the decay of macroalgae biomass. Macroalgae have higher decomposition rates than seagrasses. Examination of the relationship between degrada-tion rates and oxygen consumption rates of phytoplankton, macroalgae and SAV would be useful. However, decay rates vary by species, so the effects on local oxygen conditions may vary depending on the prevalent species of an area. One participant suggested nighttime monitoring of oxygen to understand that portion of the dissolved oxygen cycle. There is also a need to monitor dissolved oxygen in the canals to understand the diel oxygen cycles in these areas and relate these cycles to trends in macroalgal biomass. Water quality in these areas can change rapidly, so we need to understand if and how large die offs of macroalgae influence these systems. Other questions that were raised include: Do die-offs affect chlorophyll concentrations or TN? Do these large die offs of macroalgae influence the occurrence of harmful algal blooms? Is macroalgae biomass (N content) enough to support increased phytoplankton chlorophyll *a* following decomposition of macroalgae - how does this source compare to other N sources?

Trace metals also need to be examined in some areas to see what metals are accumulating in macroalgal tissue, to determine if metals are moving through the system due to bioaccumulation.

A suggestion was made to examine long term fisheries data to determine if there are significant trends in individual populations or the community. Observed trends need to be analyzed in terms of changes in water quality or vegetation characteristics to determine if there have been significant changes in fish habitat. This would enhance our understanding of the effects of macroalgae on usable living resources.

Additional recommendations were made to examine the influence of temperature changes (e.g., warmer summer tempertures), light limitation, and land use changes that might affect nutrient loads in order to determine if the changes in the macroalgal community are natural or being fueled by anthropogenically driven changes. Long term temperature differences (earlier, warmer summers and inter-annual changes in spring and winter temperatures) and hydrodynamics may mask nutrient responses and so we need to be aware of potential impacts on macroalgae abundances, even if we can not control them through management actions.

The light field (K_d) should be examined in areas where SAV and macroalgae grow or could grow. It was suggested that historic secchi data (spring, summer, fall K_d) be checked for bottom areas showing ~100 microEinsteins/m^2/sec. Some macroalga~~e~~ need less light than seagrasses, thus a better understanding of the competition for light would allow us to determine the effects of macroalgal blooms on seagrasses. It was noted that present secchi data (1 observation/month) may be too infrequent in this area where wind stirs sediments which have different reflectivities. There was a suggestion to sample a transect down the axis of Chincoteague Bay (e.g., starting around South Point and heading south) and determine the average light availability in April and May. Repeated measures over several years would represent the range of conditions and allow us to better understand the influence of light availability on the vegetation in that area. It was noted that secchi is often on the bottom in these embayments and therefor a light meter should be used for this sampling.

The group discussed the effects of small scale bathymetry changes, but was uncertain of how these small scale changes influence macroalgal presence and abundance. This discussion was based on the observation that deepening of Tampa Bay, where decreases in nuisance macroalgal abundances were noted, may have changed the hydrodyamics and changed the flushing rates of nutrients and other factors that might have favored macroalgal growth. Thermal mapping of direct groundwater discharges to the bays was discussed. MD Geologic Survey sediment ammonia data from Coastal Bays should be examined to see if there is an increase in macroalgae in high ammonia areas.

One group participant suggested developing habitat suitability indices for macroalgae. These indices could then be used to predict and map suitable habitat.

The discussion ended with several suggestions involving modeling and further analysis of data. The need for a land use change model was mentioned, and it was recommended that we see if this has been done. Final comments were made that an integrated analysis be done, similar to what has been done for the Potomac River under the auspect of the Chesapeake Bay Program.

Recommended Actions:

1. Analyze long term data for any changes (mean summer, interannual) in water temperature.
2. Groundwater is a priority for research (need to **refine the total nutrient budget**).
3. Determine if any trace metal accumulation in macroalgae tissue is occuring.
4. Evaluate segment wide estimates of nutrients to determine storage potential.
5. Implement additional diel monitoring of oxygen to understand daily cycles of DO